SEMI-ANNUAL REPORT

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OCEAN OBSERVATIONS WITH EOS/MODIS:

Algorithm Development and Post Launch Studies

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Preamble

As in earlier reports, we will continue to break our effort into six distinct units:

- Atmospheric Correction Algorithm Development
- Whitecap Correction Algorithm
- In-water Radiance Distribution
- Residual Instrument Polarization
- Pre-launch/Post-launch Atmospheric Correction Validation
- Detached Coccolith Algorithm and Post-launch Studies

This separation has been logical thus far; however, as launch of AM-1 approaches, it must be recognized that many of these activities will shift emphasis from algorithm development to validation. For example, the second, third, and fifth bullets will become almost totally validation-focussed activities in the post-launch era, providing the core of our experimental validation effort. Work under the first bullet will continue into the post-launch time frame, driven in part by algorithm deficiencies revealed as a result of validation activities.

An addition to this report is a description of our planned activities for FY99 (Appendix 1). Our next Semi-Annual Report will address the progress made on this plan.

Abstract

Significant accomplishments made during the present reporting period:

- Installed spectral optimization algorithm in the SeaDas image processing environment and successfully processed SeaWiFS imagery. The results were superior to the standard SeaWiFS algorithm (the MODIS prototype) in a turbid atmosphere off the US East Coast, but similar in a clear (typical) oceanic atmosphere.

- Inverted ACE-2 LIDAR measurements coupled with sun photometer-derived aerosol optical thickness to obtain the vertical profile of aerosol optical thickness. The profile was validated with simultaneous aircraft measurements.

- Obtained LIDAR and CIMEL measurements of typical maritime and mineral dust-dominated marine atmosphere in the U.S. Virgin Islands. Contemporaneous SeaWiFS imagery were also acquired.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1998 there are seven objectives under this task. Objectives (i) and (ii) below are considered to be the most critical. If the work planned under objective (i) is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral optimization" algorithm. The initial realization of the algorithm will be to provide a flag that will signal the probable presence of absorbing aerosols, and indicate that the quality of the derived products cannot be assured. Later realizations will provide an atmospheric correction in the presence of absorbing as well as nonabsorbing aerosols.

(ii) We need to test the basic implementation of the MODIS atmospheric correction algorithm with actual ocean color imagery. We will do this with SeaWiFS imagery.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed as time permits in CY 1998.

(iv) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a model to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We need to study the efficacy of the present atmospheric correction algorithm for removal of the aerosol effect from the measurement of the fluorescence line height.

(vi) We need to examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing out-of-band corrections to MODIS.

b. Work Accomplished:

(i) We consider this task to be one of our most important atmospheric correction activities of 1998 [the other is item (ii) above: testing MODIS algorithms with SeaWiFS imagery], and as such, the major part of our effort on atmospheric correction will be focussed on it. We have implemented the spectral optimization algorithm described by Chomko and Gordon [R. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Use of the Junge power-law aerosol size distribution with variable refractive index to handle aerosol absorption, Applied Optics, 37, 5560-5572 (1998)], in which power-law size distributions are utilized, in the SEADAS image processing environment. The power-law distribution allows a straightforward interpolation to size distributions that are not part of the candidate set. We also interpolate on the real and imaginary parts of the complex refractive index. Thus, a complete spectrum of models can be generated from a relatively small candidate set. We then use standard optimization techniques to find the best fitting set of parameters.

Although incomplete, the first test of the spectral optimization algorithm (SOA) is very encouraging. The figure on the next page compares the performance of the SOA with the NASA standard SeaWiFS algorithm (NSSA) over the Middle Atlantic Bight (MAB) for days 279 and 281 of 1997. The atmosphere over the MAB was very clear on day 281 and the NSSA and SOA yielded comparable phytoplankton pigment concentrations. In contrast, on day 279 the atmosphere over the MAB was very turbid, and there were significant differences between the NSSA- and SOA-derived pigment concentrations. Since the pigment concentration is unlikely to undergo gross changes in the MAB in two days at this time of the year, and since the SOA pigment concentrations are consistent for the two days, while the NSSA concentrations are not, these images suggest a superior performance for the SOA. We are in the process of preparing a detailed report of these results and will included it in the next semi-annual report.

We started a major effort to understand the optical properties of desert dust transported over the oceans. This is being carried out in conjunction with R. Evans. Cyril Moulin has started as a postdoc on the project in August, and is working nearly full time on this problem. The plan is to use SeaWiFS imagery from the Tropical Atlantic acquired this summer, along with the results from the Virgin Islands field experiment (see **5.b.ii**, and Appendix 2), to delineate the dust properties. In addition, we are using imagery from the Mediterranean (closer to the dust source) in conjunction with LIDAR data acquired in Rome.

(ii) We are acquiring SeaWiFS imagery on a regular basis and, with R. Evans, prepared an end-to-end test of the performance of the MODIS algorithm in its present state. To effect this we created a set of SeaWiFS-specific LUTs, but in a format required by the MODIS code. Evans' group has reformated SeaWiFS imagery into the MODIS format, and thus, we can test the MODIS codes using SeaWIFS-simulated MODIS data. Thus far the tests have been successful, i.e., MODIS code running SeaWiFS data in the MODIS format reproduced well the SeaWiFS code processing SeaWiFS data.

(iii) None. In the light of the success of our spectral optimization algorithm, we may have to make significant modifications in our original strategy. This task has been put on hold to free resources for examination of task (i). The issues will be addressed during CY 1999 with the goal of having a post-launch implementation strategy in place during CY 1999.

(iv) We continued the development of an oceanic BRDF model. Specifically, the magnitude of the Raman component has been computed as a function of the pigment concentration.

(v) No work was carried out on this task.

(vi) No work was carried out on this task.

(vii) Now that we have the MODIS relative spectral response (RSR) functions, we have started to incorporate them into the algorithms following the procedures described by Gordon (1995) ["Remote sensing of ocean color: a methodology for dealing with broad spectral bands and significant out-of-band response", Applied Optics, 34 8363-8374 (1995)]. We have computed the band-

Table 1: Band-averaged quantities needed to compute the Rayleigh reflectance and the Ozone transmittance for the MODIS bands.

λ (nm)	Band (i)	$\langle \tau_r(\lambda) \rangle_{F_0 S_i}$	$\langle F_0(\lambda) \rangle_{S_i}$ mW/cm$^2\mu$m sr	$\langle k_{Oz}(\lambda) \rangle_{F_0 S_i}$ ($\times$1000)
412	8	0.3167	170.37	1.47
443	9	0.2377	186.50	3.78
488	10	0.1610	191.82	22.21
531	11	0.1135	188.57	65.66
551	12	0.0999	187.16	83.22
667	13	0.0446	154.15	48.69
678	14	0.0417	149.88	39.95
748	15	0.0286	128.07	12.02
869	16	0.0156	97.30	3.75

averaged quantities required to compute the Rayleigh reflectance [$\langle \tau_r(\lambda) \rangle_{F_0 S_i}$ and $\langle F_0(\lambda) \rangle_{S_i}$ (See

Gordon (1995) for the notation)] and the Ozone transmittance $[\langle k_{Oz}(\lambda)\rangle_{F_0 S_i}]$. These are provided in Table 1.

In addition, we examined the influence of the water vapor absorption bands on the computation of the Rayleigh reflectance. For MODIS, the error in ignoring water vapor (up to a concentration of 3.3 g/cm^2) is a maximum of 0.25% (for Band 15). For the other spectral bands, the error is $< 0.1\%$. In contrast, for SeaWiFS the maximum error is 0.55%.

c. Data/Analysis/Interpretation: See item **b** above.

d. Anticipated Future Actions:

(i) We will continue testing the new spectral optimization algorithm using SeaWiFS imagery. In particular, we need to evaluate it with more imagery and different aerosol types. Also, we need to understand the reason for the dramatic improvement of the SOA over the NSSA in the figure following page 4, along with understanding why the performance of the NSSA (the MODIS prototype) is so poor in this case.

(ii) We shall continue testing the prototype MODIS algorithm with SeaWiFS imagery until MODIS imagery becomes available.

(iii) None. The cirrus cloud issue in the presence of our "spectral optimization" method needs to be explored. We will resolve the "spectral optimization" questions first.

(iv) An ocean BRDF model is being tested by comparison with experimental data obtained at the MOBY site and during MOCE-4. This testing will continue into CY 1999. (See **5** below).

(v) None.

(vi) None.

(vii) We will derive the functions needed to incorporate the out-of-band influence on the aerosol component of the atmospheric correction algorithm (Gordon, 1995), and provide LUT's for Rayleigh reflectance that are specific to the MODIS band characteristics.

f. Publications:

R. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Use of the Junge power-law aerosol size distribution with variable refractive index to handle aerosol absorption, *Applied Optics*, **37**, 5560–5572 (1998).

H.R. Gordon, Contribution of raman scattering to water-leaving radiance: A reexamination. (Submitted to *Applied Optics*.)

2. Whitecap Correction Algorithm (with K.J. Voss).

As the basic objectives of the experimental portion of this task have been realized (acquiring whitecap radiometric data at sea), experimental work is being suspended until the validation phase, except insofar as the radiometer is being operated at sea when it is sufficiently important to do so, e.g., the SeaWiFS Initialization Cruise (MOCE-4). Our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract. In addition, we need to reanalyze the Tropical Pacific whitecap data because of the surprisingly low reflectance increase due to whitecaps that we measured there. This is a unique data set, as it was acquired in the trade winds with moderately high winds (8-12 m/s) and practically unlimited fetch and duration. This will better bound the limits of oceanic whitecap reflectance.

a. Near-term Objectives:

Operate the radiometer at sea to maintain experience in preparation for the validation phase. Reanalyze data acquired during the Tropical Pacific cruise.

b. Task Progress:

A strategy has been developed that we believe will improve the analysis of the whitecap data; however, the postdoc identified for the reanalysis has accepted a position elsewhere (due to uncertainties in MODIS funding), so no progress has been made on whitecap data analysis of either the Tropical Pacific or MOCE-4 cruises.

c. Data/Analysis/Interpretation: See item **b** above.

d. Anticipated Future Actions:

We will begin the reanalysis of the Tropical Pacific data with the goal of submitting a revised manuscript on whitecap reflectance by the end of the summer.

e. Publications: None.

3. In-water Radiance Distribution (with K.J. Voss).

a. Task Objectives:

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle. This is the experimental component of our BRDF modeling.

b. Work accomplished:

No new measurements were made of oceanic BRDF's during this reporting period.

c. Data/Analysis/Interpretation: None (but see **1.b.(iv)**).

d. Anticipated future actions:

We will be participating in INDOEX during January to April of 1999, as well as the MODIS initalization cruise. Oceanic BRDF's will be included in our suite of measurements. We will concentrate on data analysis after INDOEX.

e. Problems/Corrective actions: None.

f. Publications: None.

4. Residual Instrument Polarization.

The basic question here is: if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction, and how can we correct for these effects?

a. Task Objectives: None.

b. Work Accomplished: None.

c. Data/Analysis/Interpretation: None.

d. Anticipated Future Actions:

This task is now basically complete. All that remains is incorporating the SBRS/MCST polarization-sensitivity data into the existing polarization correction module, when they become available.

e. Problems/Corrective Actions: None

f. Publications: None.

5. Pre-launch/Post-launch Atmospheric Correction Validation (with K.J. Voss).

a. Task Objectives:

The long-term objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the oceans to assess the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this required obtaining long-term time series of the aerosol optical properties in typical maritime environments. This was achieved using a CIMEL sun/sky radiometer. This radiometer is identical to those used in the AERONET Network (in which we are a participant).

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation could not be used (due to the motion of the ship) for this purpose. The required instrumentation consisted of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises as well as to build a climatology of the vertical distribution of absorbing aerosols. This is accomplished with a LIDAR system, which we have modified for ship operations. This LIDAR is also needed to detect the presence (or absence) of thin cirrus during the initialization/calibration/validation cruises.

(iii) The third objective was to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This required a critical examination of the effect of radiative transfer on "vicarious" calibration exercises.

(iv) The forth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, SeaWiFS ...) to validate and fine-tune the correction algorithm.

b. Work Accomplished:

(i) We have been operating the CIMEL instrument in the Dry Tortugas continuously during most of 1998. It has worked well (even surviving Hurricane Georges). These data are avaliable as part of AERONET, and have been used by others to study the validity of aerosol retrievals with SeaWiFS, e.g., Wang et al., "Remote sensing of the aerosol optical thickness from SeaWiFS in comparison with insitu measurements," Submitted to APLS99, 18-22 Jan., 1999, Meribel, France.

(ii) The Micro Pulse Lidar (MPL) along with a CIMEL were deployed in the U.S. Virgin Islands during June and July 1998 to try to observe the vertical distribution and optical properties of Saharan dust. Successful observations were made during both dust and dust-free periods. A report describing the experiment is provided in Appendix 2. We had to have the MPL unit repaired (it failed after the Virgin Islands experiment) and have procured a spare power supply to ensure against similar failures in the winter-spring INDOEX experiment. The unit is now back in Miami being prepared for INDOEX.

Aureole and sky camera data acquired during the MOCE-4 cruise are still being reduced. A paper describing our aureole camera has been prepared and submitted for publication to *JAOT*. It is included as Appendix 3.

(iii) The theoretical aspects of this work have been completed. The next phase is to use surface measurements to predict top-of-atmosphere radiance.

(iv) We have prepared a duplicate version of the MODIS algorithm code to use the SeaWiFS spectral bands. This is being used to test the MODIS code with SeaWiFS data. (See Section **1-ii**.)

c. Data/Analysis/Interpretation:

(i) A paper based on a long-term study of aerosols over the ocean has been submitted to *JGR* and is included here as Appendix 4. It confirms the notion that high aerosol optical thicknesses over the Tropical Atlantic and Caribbean are almost always due to mineral dust.

(ii) Preliminary analysis of our MPL data from the U.S. Virgin Islands deployment is provided in Appendix 2.

Analysis of the data resulting from our participation in ACE-2 (June-July 1997) is nearly complete, and several publications are being prepared. Our main contribution was in providing calibrated MPL and CIMEL data to delineate the vertical distribution of the aerosol and the optical properties. Appendix 5 is a draft of a paper comparing our MPL prediction of the vertical distribution of the aerosol optical depth with direct aircraft measurements. It is being submitted to a special issue of *Tellus* devoted to ACE-2. As far as we know, this is the first such successful comparison. It shows that the profile of optical depth can be retrieved from the MPL given surface optical depth measurements, e.g., by a sun photometer.

d. Anticipated Future Actions:

(i) We will continue to keep the CIMEL operating in the Dry Tortugas, including the monthly maintenance checks.

(ii) Our main focus will be our participation in INDOEX. Reduction of the data from the Virgin Islands, as well as MOCE-4 will be suspended until the end of INDOEX.

(iii) We attempt to use data acquired during MOCE-4 (once the analysis is complete) to effect the vicarious calibration SeaWiFS Band 8 (865 nm).

(iv) See Section **1.d.(ii)**

e. Problems/corrective actions: None.

f. Publications:

A. Smirnov, B. Holben, I. Slutsker, E.J. Welton, and P. Formenti, "Optical properties of Saharan dust during ACE 2," *Jour. Geophys. Res.*, **103D** 28,079–28,092 (1998).

E.J. Welton, K.J. Voss, D.L. Savoie, and J.M. Prospero, "Measurements of Aerosol Optical Depth over the North Atlantic Ocean: Correlations with Surface Aerosol Concentrations" (Submitted to *Jour. Geophys. Res.*).

J.M. Ritter and K.J. Voss, " A new instrument to measure the solar aureole from an unstable platform." (Submitted to *Jour. Atmos. Ocean. Tech.*).

B. Schmid, P.B. Russell, J.M. Livingston, S. Gasso, D.A. Hegg, D.R. Collins, R.C. Flagan, J.H. Seinfeld, E. Ostrom, K.J. Noone, P.A. Durkee, H.H. Jonsson, E.J. Welton, K.J. Voss, H.R. Gordon, P. Formenti, M.O. Andreae, V.N. Kapustin, T.S. Bates, and P.K. Quinn, "Clear column closure studies of urban-marine and mineral-dust aerosols using aircraft, ship, and ground-based measurements in ACE-2," (Submitted to ALPS99, 18–22 January 1999, Meribel, France).

B. Schmid, J.M. Livingston, P.B. Russell, P.A. Durkee, H.H. Jonsson, D.R. Collins, R.C. Flagan, J.H. Seinfeld, S.A. Gasso, D.A. Hegg, E. Ostrom, K.J. Noone, E.J. Welton, K.J. Voss, H.R. Gordon,

P. Formenti, and M.O. Andreae, "Clear sky closure studies of lower tropospheric aerosol and water vapor during ACE-2 using airborne sunphotometer, airborne in-situ, space-borne, and ground-based measurements." (To be submitted to *Tellus* Special Issue on ACE-2)

E.J. Welton, K.J. Voss, H.R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J.M. Livingston, P.B. Russell, P.A. Durkee, P. Formenti, and M.O. Andreae, "Ground-based Lidar Measurements of Aerosols During ACE-2: Instrument Description, Results, and Comparisons with other Ground-based and Airborne Measurements." (To be submitted to *Tellus* Special Issue on ACE-2)

6. Detached Coccolith Algorithm and Post Launch Studies (W.M. Balch).

a. Task Objectives:

Our MODIS work during involves understanding all aspects of the influence of suspended calcium carbonate particles on inherent optical properties in the sea. Work during this reporting period focused on several areas: processing cell count samples; merging atomic absorption data, particulate organic carbon data, and scattering data from MODIS pre-launch cruises in the Gulf of Maine; preparation, submission, or revision of three MODIS-related manuscripts; participating in another MODIS pre-launch cruise to the Gulf of Maine to examine in situ properties of calcite particle; and analysis of calcite optical properties from the Arabian Sea.

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focused on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scattering, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this reporting period have been:

(1) Working up data from our June '98 MODIS Gulf of Maine cruise.

(2) Final pre-publication formatting of JGR manuscript on coccolith scattering properties.

(3) Continued microscope cell/coccolith counts for latest samples from the Gulf of Maine.

(4) Final publication of a paper on coccolith optical properties (with Ken Voss and Katherine Kilpatrick.

(5) Completion of 11 one-day pre-launch cruises in the Gulf of Maine in which samples for coccolith concentration, suspended calcium carbonate and optical properties of these particulates were enumerated.

For perspective on the directions of our work, we provide an overview of our previous activities:

Jan-June 1995: Research focus – chemostat cultures (in which algal growth rate was precisely controlled) and we examined how the optical properties of these calcifying algae changed as a function of growth.

July-Dec 1995: Research focus – shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian Sea, measuring coccolithophore abundance, production, and optical properties.

Jan-June 1996: Research focus – field calcite distributions, during two Gulf of Maine cruises, one in March and one in June.

July-Dec 1996: Research focus – participated on another cruise to the Gulf of Maine and processed samples from the Gulf of Maine.

Jan-June 1997: Research focus – continued processing samples from our previous cruises, upgraded our laser light scattering photometer used in all of the calcite scattering measurements, performed another pre-launch cruise on calcite particle optics in the Gulf of Maine, and analyzed our results from the MODIS-funded flow cytometer work.

July-December 1997: Research focus – continued building our data base on calcite-dependent scattering with a cruise to the Gulf of Maine in November 1997. Work was also performed on processing the data from the June 1997 cruise. The results from the flow cytometer work were submitted for publication.

Jan-June 1998: Research focus – worked-up results from our November '97 Cruise, participated in a pre-launch cruise in June '98, finalized data merging and processing for all previous cruises, integrated the data stream for surface radiance into the suite of optical parameters which we measure [which was one of the issues from our MODIS ATBD review that was suggested for connecting the inherent optical properties (which we measure) to the water-leaving radiance (which the satellite will measure)]. Lastly, we put considerable time into preparation and publishing of earlier results.

b. July-December 1998:

We completed work-up of our June 1998 cruise in the Gulf of Maine aboard the R/V Albatross. As with the November 1997 cruise, calcite-dependent backscattering commonly accounted for 10-20% of total backscattering. Even with the low light conditions, coccolithophores were still remarkably abundant in the Gulf of Maine. We formerly interpreted strong coccolith influence on particle optics as a "summer-only" issue but it now can be clearly considered a year-round phenomenon. Specifically, we encountered a coccolith patch in 8°C water SW of Nova Scotia. This is the last place we ever expected to see coccolithophores, given the strong mixing and cool temperatures. Since we collected AC-9 data of absorption and attenuation (which by difference gave us scattering), then we have been processing the data to calculate $\widetilde{b_b}$ (the backscattering probability b_b/b) and see how this varies with the standing stock of chlorophyll and calcium carbonate.

Given the future plan for more Gulf of Maine cruises, as well as our SIMBIOS activities, we have written new software to merge the various data sets into one file that can be submitted to NASA's SeaBass data archive. The software (which performs vicarious calibrations, offset corrections, plus calculating "derived quantities" has now been through 3 sets of revisions to streamline it and make it more efficient. This software will considerably reduce the time currently required to quality control the numbers and produce hydrographic plots of the inherent optical properties (a, b, c, b_b, calcite-dependent backscattering, $\widetilde{b_b}$, temperature, salinity, and fluorescence).

c. Data/Analysis/Interpretation: See **b**.

d. Anticipated Future Actions:

Work in the next reporting period will address several areas:

(1) Suspended calcite analyses from the Gulf of Maine cruise series.

(2) Publication of *JGR* manuscript on coccolith scattering properties (January 1999 issue).

(3) Completion of a cruise in the Gulf of Mexico, doing a line between Tampa and Progresso, Mexico, followed by a trip up the entire eastern U.S., back to the Gulf of Maine (March and April 1999). This will be a one month campaign.

(4) Continuation of microscope cell/coccolith counts for latest samples from the Gulf of Maine, and Gulf of Mexico.

(5) Utilization of 20 more days at sea in the Gulf of Maine during the summer and fall of 1999.

e. Problems/Corrective Actions: None

f. Publications:

Voss, K., W. M. Balch, and K. A. Kilpatrick, "Scattering and attenuation properties of Emiliania huxleyi cells and their detached coccoliths," *Limnol. Oceanogr.* **43** 870–876 (1998).

Balch, William M., David T. Drapeau, Terry L. Cucci, and Robert D. Vaillancourt, Katherine A. Kilpatrick, Jennifer J. Fritz. "Optical backscattering by calcifying algae-Separating the contribution by particulate inorganic and organic carbon fractions," *Jour. Geophys. Res.* (In press).

Milliman, J., P.J. Troy, W. Balch, A.K. Adams, Y.-H. Li, and F.T. MacKenzie, "Biologically-mediated dissolution of calcium carbonate above the chemical lysocline?" *Deep Sea Res.* (In press).

Graziano, L., W. Balch, D. Drapeau, B. Bowler, and S. Dunford, "Organic and inorganic carbon production in the Gulf of Maine" *Cont. Shelf Res.* (Submitted).

Balch, W. M., D. Drapeau, J. Fritz, and B. Bowler, "Calcification rates in the Arabian Sea," Submitted to *Deep Sea Res.* Special Issue on the Arabian Sea (Submitted).

7. Other Activities.

The PI participated in the MODIS Science Team meeting at University of Maryland (December 15 and 16, 1998). He also presented the following papers at scientific meetings.

H.R. Gordon, K.J. Voss, J.W. Brown, P.V.F. Banzon, R.E. Evans, D.K. Clark, L. Kovar, M. Yuen, M. Feinholz, and M. Yarbrough, SeaWiFS Calibration Initalization: Preliminary Results. *Ocean Optics XIV*, Kona, Hawaii, November 11-13, 1998.

H.R. Gordon, The NIMBUS-7 Coastal Zone Color Scanner: A Retrospective. Invited paper, Americal Geophysical Union Fall Meeting, San Francisco, CA, December 6-10, 1998.

8. Publications and Submissions 1998.

H.R. Gordon, Vicarious calibration of ocean color sensors, *Remote Sensing of Environment*, **63**, 265–278 (1998).

H. Yang and H.R. Gordon, Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over Land: Simulations, *Applied Optics*, **37**, 978–997 (1998).

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflectance of whitecaps: Instrumentation, calibration, and performance in coastal waters, *Jour. Atmos. Ocean. Tech.*, **15**, 496–509 (1998).

D.J. Diner, J.C. Beckert, T.H. Reilly, C.J. Bruegge, J.E. Conel, R.A. Kahn, J.V. Martonchik, T.P. Ackerman, R. Davies, G.A.W. Gerstl, H.R. Gordon, J-P. Muller, R. Myneni, P.J. Sellers, B. Pinty, and M.M. Vestraete, Multi-angle Imaging SpectroRadiometer (MISR) Instrument Description and Experiment Overview, *IEEE Transactions on Geoscience and Remote Sensing*, **36**, 1072–1087 (1998).

J.V. Martonchik, D.J. Diner, R.A. Kahn, T.P. Ackerman, M.M. Verstrate, B. Pinty, and H.R. Gordon, Techniques for the Reetrieval of Aerosol Properties Over Land and Ocean Using Multiangle Imaging, *IEEE Transactions on Geoscience and Remote Sensing*, **36**, 1212–1227 (1998).

W.E. Esaias, M.R. Abbott, Otis B. Brown, J.W. Campbel, K.L. Carder, D.K. Clark, R.L. Evans, F.E. Hoge, H.R. Gordon, W.M. Balch, R. Letelier, and P. Minnett, An overview of MODIS capabilities for ocean science observations, *IEEE Transactions on Geoscience and Remote Sensing*, **36**, 1250–1265 (1998).

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